



Production-phase greenhouse gas emissions arising from deliberate withdrawal and destruction of fresh fruit and vegetables under the EU's Common Agricultural Policy

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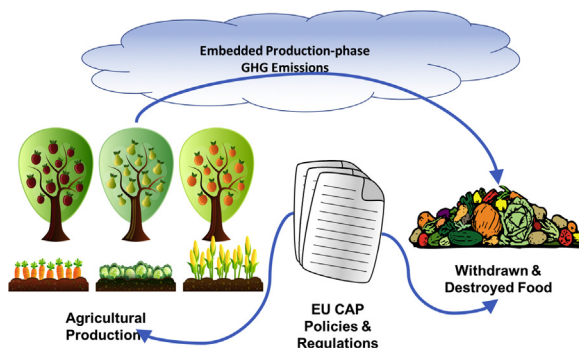
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HIGHLIGHTS

- EU CAP withdrawal mechanism has resulted in substantial avoidable food losses.
- This policy has direct climate and food production/provision impacts.
- We quantify the climate cost of destroyed FFV from production-phase GHG emissions.
- GHG emissions are 5.1 Mt CO₂e between 1989 and 2015; CMO Regime emissions fell 95%.
- The mechanism is still used, and destruction levels static at 60% of withdrawals.

GRAPHICAL ABSTRACT



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ABSTRACT

Since 1962 the Common Agriculture Policy (CAP) of the European Union (EU) has enabled payment of subsidy to some food producers for withdrawal of specific commodities – including fresh fruit and vegetables (FFV) – where market prices have fallen below a pre-set level. These deliberate withdrawals have led to large amounts of usable food (~60% of withdrawals) being destroyed on farms across the EU. Such wasted food incurs a significant climate change cost through its production-phase greenhouse gas (GHG) emissions. Here, we assess the magnitude of this FFV withdrawal and destruction, its spatial and temporal trends, and its associated GHG emissions between 1989 and 2015. We find the total mass of avoidable FFV losses occurring as a result of these EU CAP market interventions for this 26-year period to be 23.6 Mt. The production-phase GHG emissions associated with the withdrawn FFV that was subsequently destroyed amount to 5.1 Mt CO₂e over this period. We also find that, with each successive Common Market Organisation (CMO) reform there has been a marked reduction (~95% between 1989 and 2015) in the quantity of such deliberate withdrawals. Surprisingly, however, whilst the absolute quantity of FFV withdrawn and destroyed has fallen, the proportion of withdrawals that is destroyed remained roughly static at an average of about 60%. Finally, to inform debate on action needed to address FFV specifically, and food loss and waste more generally, we highlight potential scenarios and mechanisms to reduce withdrawals, avoid FFV destruction and improve alternative use of withdrawn food in the future.

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1. Introduction

1.1. Avoidable food loss & waste

The avoidable loss or waste of food is an inefficient use of resources (Porter and Reay, 2016), not discounting other potential environmental impacts of agriculture such as land use change, soil degradation, and pollution run-off (IPCC, 2000, sec. 1.4). These resources include, amongst others, labour, fertilisers, pesticides, and finance. The growing of food for human consumption generates significant greenhouse gas (GHG) emissions, with global agriculture responsible for 10–12% of total anthropogenic emissions (Smith et al., 2014, p. 822). These are GHG emissions that arise from food production activities. Everything we eat represents a particular share of those emissions. What we don't eat or otherwise destroy – food loss and waste (FLW) – is representative of GHG emissions that may have been avoided by producing less or using it more efficiently.

Much of the literature on FLW to date has focused on estimating the quantity of food that leaves the food supply chain. The first large-scale study of food waste, Monier et al. (2010), examines the phenomenon within the European Union (EU). They estimate 89 Mt of food is lost or wasted from the farm-gate to the consumer (i.e. excluding wastage occurring on the farm itself), equivalent to 170 Mt CO₂e in embedded GHG emissions. At the global level, Gustavsson et al. (2011) estimates food wastage across the food supply chain (FSC), including on-farm losses, to be approximately one-third of all production (by mass). One of their main conclusions is that most wastage occurs at the final, consumer, stage of the FSC in relatively wealthy countries, whilst poorer countries see relatively more losses in the early stages (i.e. production and storage). Hiç et al. (2016) points to oversupply of food, particularly in OECD countries, as a key contributor to food waste. Porter et al. (2016) demonstrates that fruit and vegetables are the most wasted food commodities globally across the entire FSC; its wastage accounts for over 40% by mass and is the third-highest in terms of embedded emissions (behind meat and cereals) of all FLW.

1.2. EU CAP, CMOs, and market withdrawals

Implemented in 1962, the Common Agricultural Policy (CAP) was intended to provide support for agricultural operations and thereby ensure adequate food supply and support farm income of the six Western European States that crafted the Treaty of Rome (Roederer-Rynning, 2015, p. 197). Specific regulations, referred to as Common Market Organisations (CMOs), were set up for products most important to these countries; those for fruit and vegetables in 1972 (European Council, 1972). With the aim of achieving domestic food security and supporting farm income, a key policy lever of the CAP was to provide guaranteed minimum prices to farmers (Daugbjerg, 2003). The more farmers produced the more they earned, subsidised by the consumer through higher EU prices than world market forces would otherwise indicate (Ackrill and Kay, 2006; Daugbjerg, 2014). Amongst other levers to protect prices (and thereby indirectly supporting farmer income) was the potential to withdraw production surpluses from the market (DG-AGRI, 2011).

Some commodities, such as cereals and dairy, are subject to market intervention of 'buying-in', and are typically stored for selling back into the market when prices stabilise at acceptable levels (European Parliament and Council, 2013). Fresh fruit and vegetables (FFV) that are withdrawn from market, in contrast, may not be returned to the food supply chain via a sales channel; CMO regulations specify particular destinations, including destruction (European Council, 1972, 1996, 2007). Prior to 1988, when a maximum limit on CAP spending was introduced (European Council, 1988), there were no controls on the level of monetary support allocated via this policy. With less need to heed market signals, EU production increased beyond marketable levels (Ackrill and Kay, 2006). The result: before the first major CAP reform in

1992 (to address its "trade distorting impact" (Daugbjerg, 2014) and to increase its "market orientation" (DG-AGRI, 2013)), spending on support for markets and export subsidies to address excess agricultural production was over 90% of all CAP expenditure (DG-AGRI, 2011). Further CAP reforms were enacted in 2003 and 2013, to 'decouple' production from income under the single payment scheme, and introducing sustainable agriculture and 'green' direct payments, respectively (DG-AGRI, n.d.-a). Amendments to the FFV CMO regimes followed in 1996 and 2007 to achieve particular objectives. Table 1 summarises the aspects of each regime relevant to FFV withdrawals.

With the exception of 'free distribution' (i.e. donation), withdrawn FFV is no longer considered food and must be disposed of, becoming 'avoidable' food loss. Channels for such food loss include alcohol distillation, animal feed, green harvesting/non-harvesting of crops, and biodegradation (European Council, 2007). For withdrawn FFV, destruction (e.g. via composting and ploughing into soils) is a likely disposal route. Here, for the first time, we examine the climate change cost of such food withdrawal and destruction within the EU, specifically estimating the embedded production-phase emissions of such loss. Our focus is on fresh fruit and vegetables within the EU for the period 1989–2015, to provide policy-relevant insights that inform the debate on avoidable FLW.

2. Methods

We estimate annual embodied production-phase GHG emissions for destroyed FFV within the EU from the exercising of the CAP food withdrawal mechanism for the period 1989–2015. We do so using three quantifiable elements; amounts of FFV withdrawn, proportion destroyed, and production-phase GHG emissions factors of the destroyed food. The relationship is shown using the model in Eq. (1), whose factors are detailed in the paragraphs and table that follow. We also compare the elements and output of the model across the three CMO regimes identified in Table 1.

Our analysis of the embedded emissions focuses on avoidable permanent food losses – food that is safe to eat yet is withdrawn from the supply chain and destroyed. Food that is repurposed (such as to animal feed) or redirected (e.g. to charities for 'free distribution') is therefore not included in our estimates. As the CAP only directly applies to Member States, changes to EU's constituents over time are accounted for in each year. That is, only data for actual EU Member States in a given year are included in the estimates, and not all 28 (at time of writing).

$$EM_{j,t} = \sum Withdrawals_{j,t} * Destroyed_{j,t} * EF_{j,k} \quad (1)$$

where: *EM* is production-phase embedded GHG emissions, in tonnes of CO₂e; *Withdrawals* is the mass of food subjected to market intervention, in tonnes, and *Destroyed* is the fraction of *Withdrawals* that undergoes complete destruction, for commodity *j*, in year *t*. *EF* is the production-phase GHG emission factor, in tonnes of CO₂e per tonne of food, for commodity *j* in country *k* (or Europe-level if country data are not available).

Annual data for *Withdrawals* quantity and *Destruction* factors are sourced from Agrosynergie (2007), the Directorate General – Agriculture and Rural Development (DG-AGRI, n.d.-b), and personal communication from the DG-AGRI of 27 Oct 2017. Of the full period 1989–2015, there are no available *Withdrawals* data for 2008 or 2009, or *Destruction* data for 1994–1996 and 2005–2009. Different degrees of data granularity exist for different years during the period under review. The spectrum ranges from the commodity-by-country level (most granular available), to country or commodity only (least granular).

Destruction factors for the missing time periods were estimated as the average of prior years' values within the same CMO Regime for which data were available. Therefore, 1994–96 was given a *Destruction* factor of 50.3% (the average of 1989–1993) and 2005–2007 was given a factor value of 69.9% (the average of *Destruction* data for 1997–2004). For individual years of the period 2010–2015, we assumed that the

Table 1

Key aspects of CMO regulations with respect to FFV withdrawals from the market for each regime.

Sources: European Council (1972, 1996, 2007) for CMO Regimes 1–3, respectively.

Regime	CMO regulation	Objective	Market inventions	Key change(s)
1st (1989–1996)	Regulation (EEC) No 1035/72	Maintain stable prices, using market interventions when necessary, avoiding destruction when possible	Fixing of a basic and buy-in price at start of each year.	Permitted destination of withdrawals are specified, including 'non-food uses'.
2nd (1997–2007)	Council Regulation (EC) No 2200/96	Change perception of withdrawals as an acceptable alternative outlet to the market.	Specific flat rates for withdrawals of each commodity set for next six years. Typically decline 25% over time period.	Upper limit of compensation of withdrawals set at 35% of marketed value in year 1, declining to 10% by year 6. 'Free distribution' for withdrawals is emphasised. Destruction by 'composting/biodegradation' an acceptable destination.
3rd (2008–2015)	Council Regulation (EC) No 1182/2007	Improve competition and market orientation, and achieve sustainable production.	100% of 'free distribution' will be compensation (up to 5% volume limit)	Maximum compensation falls to 4.1% for withdrawals that are not 'free distribution'. All destinations of withdrawals compensated at 50% of value, including 'destruction'. Introduces 'green' and 'no-harvest' crisis management tools, that have same effect as withdrawals.

values for 'Other Destination' provided by DG-AGRI were equivalent to *Destruction*. Where commodity-level data were not available (i.e. 1997–2004), the same *Destruction* factor was applied to all *Withdrawals* in a country.

Production-phase *Emission factors* (EFs) for the FFV commodities destroyed were derived from Porter et al. (2016). Country-level EFs are available for FFV commodities for the period 1997–2004, where destruction data were most granular in the DG-AGRI product reports (DG-AGRI, n.d.-b). For the remaining years within the time period under review, Europe-level EFs were applied (Table 2).

2.1. Data limitations & key assumptions

FFV withdrawn from the market cannot use a sales channel to re-enter the food supply chain, though it may do so via other channels. 'Free distribution' to the most needy within the bloc is one of the EU's preferred channel for food withdrawals (DG-AGRI, n.d.-c). Such withdrawn food remains within the food supply chain for human consumption. Other destinations/channels for withdrawn food include animal feed, direct distillation, and complete destruction. For the purposes of this paper, withdrawals destined for animal feed and distillation are excluded as they retain an element of use in the food supply chain. For the period 1989–2004, only the data which Agrosynergie (2007) categorises as 'Destroyed' are used to calculate embedded emissions. For 2005–7, where specific data on amounts or proportion 'Destroyed' are

not available, the average of the previous years in the 2nd CMO Regime (i.e. 1997–2004) is assumed. For the years 2010–15, data received from the EU's DG-AGRI (pers. comm., 27 Oct 2017) are only categorised as 'free distribution' or 'other destination'. For these years, we assumed the latter is fully 'destroyed'.

The data for the Regime 2 period of 1997–2007 are the most granular; the DG-AGRI produced reports that disaggregated amounts withdrawn and destroyed for most FFV commodities at the country level. Thus, country-level EFs were used where available to estimate production-phase GHG emissions; and EU-level EFs where they were not. Annual commodity-level destruction data is only available for 2010–2015 (DG-AGRI, pers. comm., 27 Oct 2017). For the period 1989–1993 and 1997–2004, we applied annual overall destruction rates from Agrosynergie (2007) to all commodities in a given year. For 1994–1997 and 2005–2007, destruction data were not available. To account for this, we applied the average destruction rate of the other years within the respective CMO regime.

3. Results

3.1. Withdrawals of fruit and vegetables

Total quantity of FFV withdrawals by EU Member States between 1989 and 2015 was 23.7 Mt. Annual average quantities fell in each successive CMO regime from 18 kt yr⁻¹ in Regime 1, to 80 kt yr⁻¹ in Regime 3 (the latter excluded 2008 and 2009 where data are unavailable; Table 3). However, an intra-Regime downward trend only occurs within the 2nd Regime of 1997–2007; the 1st and 3rd regimes do not demonstrate a strong trend in any direction. The total quantity of withdrawals at the end of the 1st and 3rd Regimes was 6% and 10% higher than at their respective beginnings (1.78 Mt vs 1.68 Mt and 67.6 kt vs 61.5 kt, respectively). In contrast, there was a 97% fall during the course of the 2nd Regime.

Reviewing FFV withdrawals by country highlights the dominance of just four EU Member States. In each year of the 1st and 2nd Regimes (i.e. between 1989 and 2007) bar one, France, Greece, Italy, and Spain together accounted for at least 90% of all FFV withdrawals. The exception was 1993, where FFV withdrawals in these four Member States represented 87% of the EU total. Total withdrawals by these Member States during the full 1989–2015 period (21.6 Mt) were 93% of the EU total. In the 1st Regime, Greece withdrew the greatest quantity of food each year except 1992, accounting for 38% (or 6.17 Mt) of FFV withdrawals in that period. The 2nd Regime similarly saw one country, Spain, dominating the use of the mechanism each year and withdrawing almost 42% (or 2.93 Mt) of all FFV between 1997 and 2007 (Fig. 1; country-level data were not available for Regime 3 and appear as 'EU-undefined' in this period for completeness).

Table 2Production phase *Emission factors* (EFs) for fruits and vegetables in Europe. EU country short forms: IT = Italy, UK = United Kingdom, SE = Sweden, DK = Denmark, NL = Netherlands, ES = Spain.

Fruit/vegetable	Emission factor (Europe-level) (t CO ₂ e t ⁻¹)	Emission factor (country-level) (t CO ₂ e t ⁻¹)
Apples	0.29	0.22 (UK); 0.19 (IT)
Pears	0.43	0.32 (UK)
Apricots	0.43	
Peaches (incl. Nectarines)	0.31	
Oranges (incl. Clementines)	0.31	0.70 (IT)
Mandarins (incl. Satsumas)	0.51	
Lemons	0.51	0.42 (IT)
Melons	1.89	1.25 (IT)
Watermelons	1.33	
Grapes	0.42	
Cauliflower & Broccoli	0.48	1.00 (SE); 0.26 (UK)
Eggplant	1.30	
Tomatoes	0.72	3.62 (DK); 0.60 (IT); 2.83 (NL); 0.30 (ES); 3.00 (SE); 5.10 (UK)

Table 3

Variation in annual mean withdrawals and destruction of food (in kt), and embedded emissions (in kt CO₂e) during the three CMO regimes. The values in brackets are standard errors.

CMO Regime	FFV withdrawn (kt yr ⁻¹)	FFV to 'free distribution' (kt yr ⁻¹)	FFV destroyed (kt yr ⁻¹)	Embedded emissions of destroyed FFV (kt CO ₂ e yr ⁻¹)	Average emission intensity of destroyed FFV (kt CO ₂ e kt ⁻¹)
1st Regime	2018	43.1	1053	365	0.18
1989–1996	(366)	(11.2)	(264)	(88.3)	(0.021)
2nd Regime	640	31.8	472	212	0.33
1997–2007	(158)	(5.3)	(130)	(55.9)	(0.011)
3rd Regime	80.2	28.2	52.0	31.1	0.39
2008–2015 ^a	(13.3)	(5.2)	(12.2)	(8.06)	(0.038)

^a Data for Regime 3 only covers the six years of 2010–2015 due to lack of availability in 2008 and 2009.

3.2. Destruction vs 'free distribution' across CMO Regimes

The CAP has undergone significant reforms three times during the period under review, in 1992, 2003 and 2013. As a result, the original 1972 CMO regulations for FFV that specify how the CAP is to be implemented were similarly updated in 1996 and 2007 (Table 1; European Council, 1972, 1996, 2007). The effect of these policy changes has been to reduce the quantity of withdrawals and permitted destruction of FFV produce suitable for human consumption.

Destruction has been the destination for the majority of withdrawals in nearly all years under review (Fig. 2); the only exceptions being the first two years of the 1st Regime (1989 and 1990). The average annual tonnage of FFV withdrawn from EU markets dropped 96% between the 1st and 3rd CMO Regimes, from an average of 2.0 Mt yr⁻¹ to 80 kt yr⁻¹. Of these amounts, an annual average of 1.1 Mt yr⁻¹ and 53 kt yr⁻¹ were destroyed, respectively. 'Free distribution' saw a 6-fold increase in its share of withdrawals between the 2nd and 3rd Regimes (from 6% to 38%). However, there was little change in the average annual quantity freely distributed between these two Regimes (30 kt yr⁻¹ vs 28 kt yr⁻¹), which is a third less than the average of 43 kt yr⁻¹ during Regime 1. At the same time, the proportion of withdrawals that was destroyed rose from 50% to 62% (Table 3).

3.3. Embedded emissions of withdrawn and destroyed FFV

Total production-phase GHG emissions of FFV withdrawn and destroyed via the CAP withdrawal mechanism during the 1989–2015 period are estimated at 5.1 Mt CO₂e. However, there has been a reduction of 91% in average annual embedded emissions of destroyed FFV withdrawals between Regime 1 and 3; from 365 kt CO₂e yr⁻¹ to 31 kt CO₂e yr⁻¹. Most of this decline occurred during the 2nd Regime,

falling from an intra-Regime peak of 595 kt CO₂e in 1999 to 23 kt CO₂e in 2007. Within this CMO Regime, embedded emissions steadily declined from the peak year (Table 3). In terms of the proportion of production withdrawn from markets, this was consistently below 3% during Regime 2, despite the existence of an upper limit of 10% for support. This contrasts with withdrawals of up to 50% of production, depending upon commodity and country, in the 1st and 2nd Regimes (Agrosynergie, 2007, p. 52). Since 2010 and under Regime 3 – where the maximum permitted withdrawal is 5% (for 'free distribution'), the proportion of production withdrawn from market has not exceeded 0.5% for any FFV commodity (DG-AGRI, pers. comm., 27 Oct 2017).

The granularity of the data available during Regime 2 allows a detailed examination of embedded emissions that can be attributed to Member States. However, there remained some proportion of destroyed FFV that was not captured at the country level in this period. This information is denoted herein as 'EU-undefined' (Fig. 3). As with the mass of FFV withdrawn, we again find a clear North/South divide in terms of attributing emissions from withdrawn FFV that was subsequently destroyed. During Regime 2, the Southern European countries of Italy, Spain, Greece, Portugal, and Cyprus accounted for 1.18 Mt CO₂e of country-attributable embedded emissions, 86% of the total 1.37 Mt CO₂e. Spain alone accounted for 45% (624 kt CO₂e) of this 'climate cost', with Greece and Italy adding a further 23% (313 kt CO₂e) and 17% (232 kt CO₂e), respectively. This division reflects differing agricultural production of Member States of withdrawal-eligible FFV commodities (eurostat, n.d.).

The proportion of embedded emissions associated with destruction of particular FFV commodities has varied during the period under review (Fig. 4), as have their absolute quantities (Table 4). Although there is generally less variation within a given CMO Regime, some trends emerge when viewed across Regimes. One such trend is the relative reduction in production-phase emissions associated with the

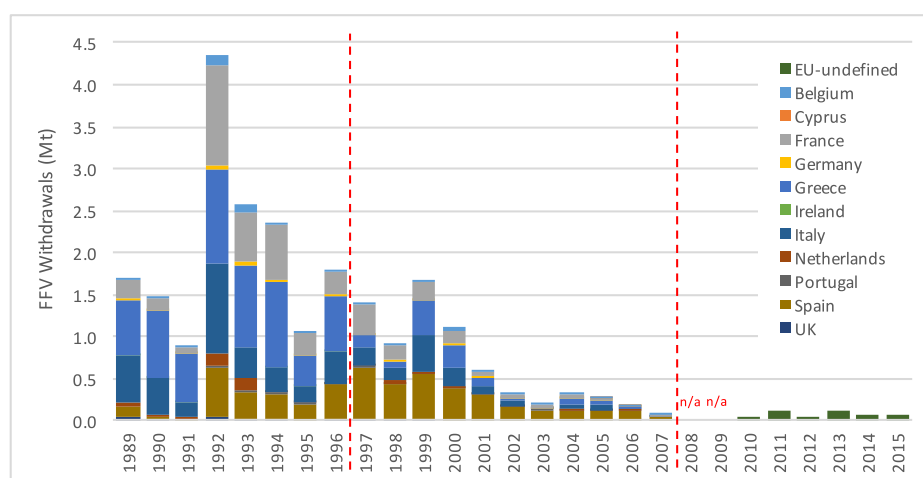


Fig. 1. Annual withdrawals of food by country (in Mt). Sources: 1989–2004, Agrosynergie (2007); 2005–2006, DG-AGRI (n.d.-b) product pages; 2010–15, DG-AGRI (pers. comm., 27 Oct 2017). Data was unavailable for 2008–9 and only EU-level aggregate data available for the period 2010–15. The dashed vertical lines separate the CMO regimes; 1st Regime (1989–1996), 2nd Regime (1997–2007), 3rd Regime (2008–2015).

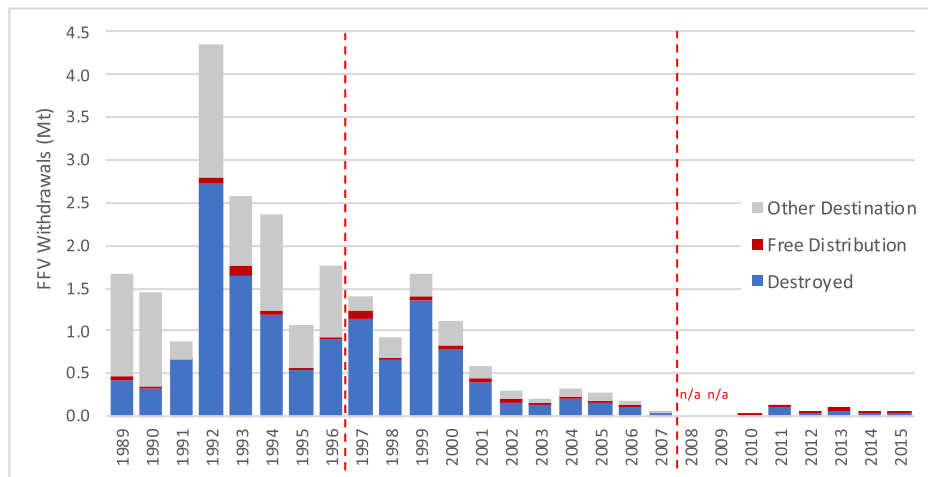


Fig. 2. Destination of food withdrawals, aggregated to EU level (in Mt). Sources: 1989–2004, Agrosynergie (2007); 2005–2007, DG-AGRI (n.d.-b), product pages; 2010–2015, DG-AGRI (pers. comm., 27 Oct 2017). No data available for 2008 or 2009. The dashed vertical lines separate the CMO regimes; 1st Regime (1989–1996), 2nd Regime (1997–2007), 3rd Regime (2008–2015).

destruction of stone fruit (e.g. peaches and nectarines) and of top fruit (apples and pears). Whereas these two commodity groups were responsible for over 60% of all embedded emissions in the 1st Regime, this fell to 15% in the 3rd Regime. In contrast, melons, which are relatively emissions intensive compared to other FFV (Table 2), saw a steady proportional increase in importance during Regimes 2 and 3. Vegetables (here comprising tomatoes, broccoli and cauliflower, and aubergines) have consistently accounted for the greatest proportion of production-phase emissions associated with destroyed food in the 2nd and 3rd Regime periods at around 40%. In 'climate cost' terms, each commodity group exhibited lower absolute annual average levels of embedded emissions from destroyed withdrawals in Regime 3 than in previous regimes where withdrawals were permitted (melons entered in Regime 2, for example).

4. Discussion

4.1. Destruction as institutional inertia during market crises: Russian ban on EU FFV exports

Once harvested, fresh fruit and vegetables deteriorate in quality with a rate that is a function of heat and humidity – a quick transfer to

optimal storage is key to maintaining quality (Blackburn and Scudder, 2009). This 'highly perishable' nature of the FFV seems to present particular challenges to minimising avoidable food losses when a market crisis occurs. One such challenge has been to reduce the proportion of withdrawn FFV that is destroyed. Despite a dramatic fall in excess of 95% in the quantities of FFV withdrawn from the market, the average proportion destroyed in CMO Regime 3 is higher than that in Regime 1 (65% vs 52%, Table 3). By their nature, crises are unexpected events. The failure to eliminate destruction of withdrawals suggests institutional inertia – once introduced, it is easier to continue to use existing provisions in the CAP than to stop and replace them (Peterson and Bomberg, 1999, pp. 142–143). When a crisis occurs, the provisions within the CAP that compensate for the use of destruction as an acceptable destination could result in an increase, albeit perhaps temporary, in the amount of avoidable food waste in the system. The following presents just such a crisis as an example.

In August 2014, Russia instituted a ban on imports of certain agri-food products from the EU, including FFV. Some have classed the ban as a retaliation for Ukraine-related sanctions imposed by the EU on Russia (Boulanger et al., 2016; Liefert and Liefert, 2015; McElDowney, 2016). Whilst predicated on international relations disagreements, the European Commission deemed it would precipitate a severe crisis for

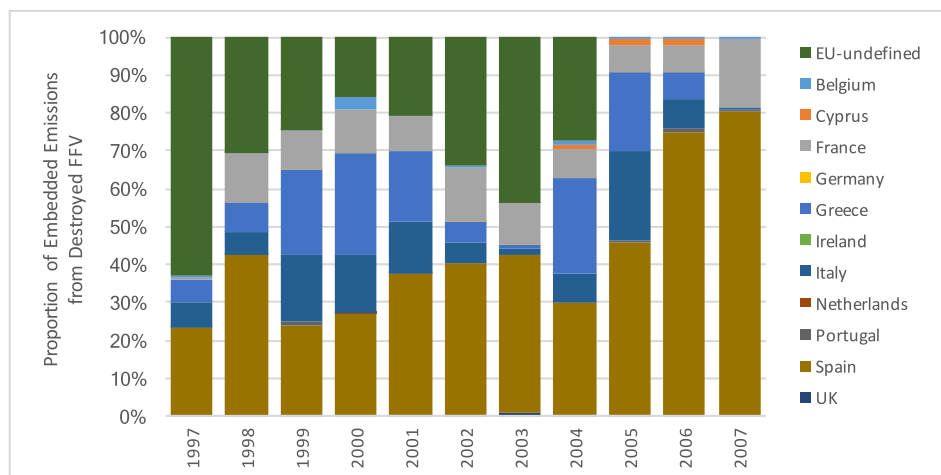


Fig. 3. Proportion of embedded emissions of destroyed food. Sources: Country-level data was aggregated from DG-AGRI (n.d.-b) commodity-level data; 'EU-undefined' data is from Agrosynergie (2007) for those commodities not captured at country-level (cauliflower & broccoli, aubergines/eggplants (EU data uses both terms interchangeably; 'aubergines' is used within this paper to refer to either), melons, and grapes).

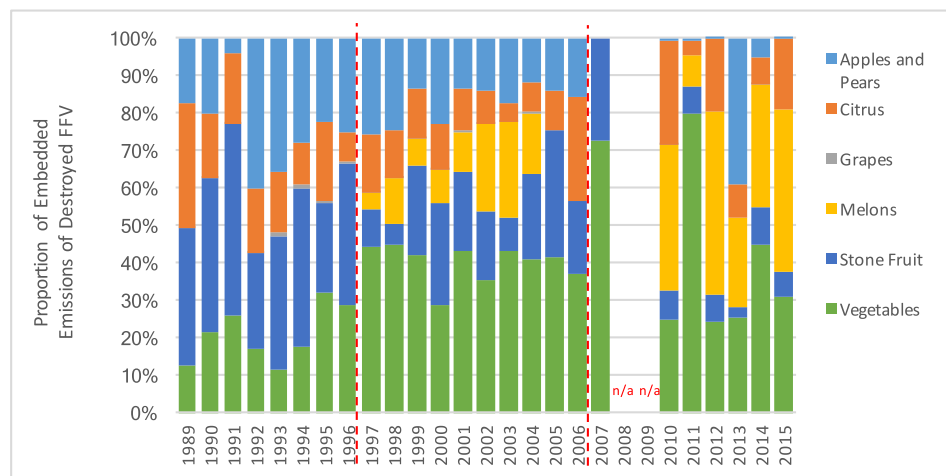


Fig. 4. Embedded emissions by commodity (in kt CO₂e) of food destroyed annually between 1989 and 2015. Sources: 1989–2004, Agrosynergie (2007); 2005–2007, DG-AGRI (n.d.-b), product pages; 2010–15, DG-AGRI (pers. comm., 27 Oct 2017). No data available for 2008–09. The dashed vertical lines separate the CMO regimes; 1st Regime (1989–1996), 2nd Regime (1997–2007), 3rd Regime (2008–2015). Due to the degree of reductions of absolute emissions between Regimes, this figure should be considered alongside Table 4 for context.

FFV producers within the EU. About 29% of EU FFV exports, valued at almost €2bn, were destined for the Russian market (McEldowney, 2016). Without that sales channel, EU FFV markets were at risk of from the excess domestic supply. In a series of Commission Delegated Regulations between 2014 and 2017, the European Commission put into place “exceptional support measures” to reduce the impact to farmers of this ban (European Commission, 2014a, 2014b, 2016, 2017). Each of these ‘temporary’ regulations waived the upper limit for FFV withdrawals, though did specify a maximum permitted tonnage that would be compensated. The measures have been fully taken up by producers, equivalent to an extra 1.1 Mt of withdrawals. Assuming 65% of these withdrawals are destroyed (the average for 2010–2015 that did not go to ‘free distribution’), this single crisis event would result in the equivalent of an extra 335 kt CO₂e of embedded production-phase emissions. Put another way, that is almost 2.5-times the estimate for total emissions for 2010–15 of destroyed FFV withdrawals in Table 3.

4.2. Using food destined for destruction via ‘free distribution’

Reallocation of withdrawn FFV may support food programmes in EU Member States. These may be organised at any level; individual charity/NGO, the Member State, or the EU. An example of an EU-level programme is the School Fruit & Vegetables programme. In the 2015–16 school year, the programme provided an average of 53 portions of FFV to 11.7 m school children in participating Member States (DG-AGRI, 2016); this is equivalent to 82.5 kt of food. Redirecting the average amount of FFV withdrawn and destroyed annually in CMO Regime 3 (52 kt, from Table 3) could increase the amount of fresh fruit and

vegetables available to the programme by over 60%. This could benefit an additional 7.5 m school children by maintaining current average portion levels, and possibly do so for less cost per portion than currently. The average cost of providing fresh fruit and vegetables to schools was €2.44 kg⁻¹ (€0.33 per portion of 135 g; DG-AGRI, 2016). To put this cost into perspective, it is over 11-times the highest price (for oranges) and 41-times the lowest price (for aubergines) the EU would pay producers for these same commodities under the withdrawal mechanism (European Commission, 2007, annex X).

Producers also benefit from redirecting to ‘free distribution’ destinations those withdrawals that would otherwise be destroyed. The EU fully funds ‘free distribution’ withdrawals, which is up to twice the level of compensation as for other destinations (DG-AGRI, n.d.-c). Withdrawals sent to organisations such as food banks, and local and third-country free food distribution schemes managed by NGOs would be eligible (European Council, 2007, art. 10, para. 4). Up to 15% more meals could be distributed to help alleviate hunger of an additional 900,000 people within the EU if the full amount of annually destroyed food were donated to, and accepted by, food banks. This estimate is based upon the 535 kt of food distributed to 6.1 million people in 2016 by members of the European Federation of Food Banks (FEBA, n.d.).

Transport costs of ‘free distribution’ are eligible for fixed rate reimbursement to the organisation incurring the costs (European Commission, 2007, art. 82). In practice, this provision may mean that the receiving organisation is required to first pay for the logistics costs of the donations. Alternatively, the producer could be liable for first paying such costs. It may be difficult for a receiving charitable organisation or the sending producer to fund the extra working capital necessary for delivery or receipt of additional food donations. Other costs that may be incurred to operationally manage the distribution of fast-perishable food such as FFV – such as cold storage and quick delivery – are not eligible for compensation. Should the fixed tariffs for transport not be sufficient to cover costs, further funding issues may arise for parties wishing to avoid unnecessarily destroying safe, edible food.

In addition to the monetary costs of transport and cold storage, energy (usually predominantly fossil fuel-based) is required to provide such services. Distributing food that is ‘extra’ to a planned system may therefore result in some increase in supply chain emissions. Presently, food available for consumption within the EU exceeds nutritional needs by 30–40% (Hiç et al., 2016), much of which ends up as waste (Gustavsson et al., 2011) or excess intake (Swinburn et al., 2009). Increasing food availability, by not withdrawing and destroying production in excess of market capacity to absorb, could increase the amount wasted in later stages of the supply chain. As a result, the embedded

Table 4
Annual means of gross and proportionate emissions attributed to main FFV commodity groups across the full 26-year time period (1989–2015) and for each respective CMO regime.

Commodity group	Emissions (kt CO ₂ e yr ⁻¹)			
	Overall (1989–2015)	Regime 1 (1989–1996)	Regime 2 (1997–2007)	Regime 3 ^a (2008–2015)
Apples & pears	53.0 (16%)	108.4 (24%)	40.2 (16%)	2.4 (8%)
Citrus	31.8 (14%)	59.6 (18%)	27.1 (11%)	3.3 (14%)
Grapes	0.5 (0.1%)	1.7 (0.4%)	0.04 (0.0%)	0.01 (0.0%)
Melons	10.3 (12%)	0 (0%)	19.2 (10%)	7.8 (33%)
Stone fruit	57.9 (22%)	125.7 (37%)	38.6 (20%)	2.1 (7%)
Vegetables	64.3 (35%)	69.6 (21%)	87.0 (43%)	15.5 (38%)

^a Data for Regime 3 only covers the six years of 2010–2015 due to lack of availability in 2008 and 2009.

emissions of that waste may be higher than if destroyed pre-farm-gate. On the other hand, the bulk of FFV lifecycle emission occur in the production phase. They can be as high as 50% of the total for poultry and as low as 10% for beef, with FFV at about 15%, on a full cradle-to-grave LCA analysis (Porter et al., 2016). If redistributed FFV displaces other produce, and so lowers production demand, it is still likely to reduce GHG emissions relative to destruction.

4.3. Sustainable Development Goals (SDGs), diets, and climate targets

In the lead up to COP 21 in Paris, the UN General Assembly adopted the 2030 Agenda for Sustainable Development, which included the 17 Sustainable Development Goals (United Nations, 2015). Whilst there are synergistic interactions between many of SDG pairs, SDG 12 as a whole ('Responsible Consumption and Production') may be at odds with many others due to competing trade-offs (Pradhan et al., 2017). These include eliminating poverty and hunger (SDGs 1 & 2), and promoting good health and well-being (SDG 3). Achieving the SDGs relies, at least in part, on increasing incomes in non-OECD countries, which is also related to increases in GHG emissions from pursuing economic development (Costa et al., 2011), changes to diets (Pradhan et al., 2013; Tilman and Clark, 2014), and higher levels of food waste by consumers relative to production (EU FUSIONS, 2016; Gustavsson et al., 2011), amongst others. Further complicating potential synergies are official national dietary guidelines to promote healthy eating that are largely incompatible to achieving the 1.5 °C climate-change ambitions of the Paris Agreement as they are skewed to protein from meat and dairy (Ritchie et al., 2018).

Reducing avoidable losses of FFV at the production stage of the agri-food supply chain can have a direct impact in a number of these areas. A higher proportion of FFV entering the supply chain can reduce the amount needed to be grown, thus lowering production emissions. FFV are key elements to a healthy diet, yet consumption within the EU is well below levels recommended by the World Health Organization; the highest reported proportion being one-third, in the UK (Eurostat, 2016). Increased availability of affordable FFV, coupled with coordinated programmes to re-educate the populace on improved consumption could benefit diets as well as climate (the latter through lower food waste and possibly less livestock-based protein). Alternatively, holding production constant and achieving a greater throughput would lower production emissions intensity – a greater 'yield to market' for the same emissions cost. Therefore, progress towards SDG 12.3 – to "halve per capita global food waste at the retail and levels and reduce food losses" earlier in the FSC (United Nations, 2015, p. 22) – can be made by producers. Having those food waste improvements feed through the downstream FSC will require changes to attitudes, behaviours, markets, and policy. The EU's Platform for Food Losses and Food Wastes is intended as a forum to bring together public and private sector stakeholders that have an interest in reducing FLW to do just this (DG-Health, 2016).

4.4. Policy successes & failures

The various reforms of the CAP and resultant CMO regimes have had the consequence of reducing FFV withdrawals. Instituting an upper limit on the proportion of individual FFV commodities that may be withdrawn, beginning with 10% during the 2nd CMO regime and tightening to 5% in the 3rd Regime, has been shown to be successful. Fewer withdrawals from the market have meant a lowering of the production-phase GHG emissions associated with this policy, as smaller quantities of FFV have been destroyed. The FFV commodity with the highest average annual withdrawal rate during Regime 3 was peaches, at 0.52% of production. Further, in this Regime there were only three instances of individual annual withdrawals greater than 1% of production; satsumas (1.25%) and pears (1.22%) in 2015 (eurostat, n.d.), and nectarines (1.03%) in 2012 (DG-AGRI, pers. comm., 27 Oct 2017). This compares

to the 1st CMO Regime when such proportions would at times exceed 20% of production (e.g. peaches in 1992–1994, and nectarines in 1992, 1994, and 1996; Agrosynergie, 2007, p. 36).

Another 'success' that might be attributed to the reforms of the CMO Regimes is the average proportion of withdrawals channelled to the neediest within the EU via 'free distribution'. This average increased with each CMO reform, from 2% in the 1st Regime to 38% in the 3rd. However, whilst the quantity of withdrawn FFV has fallen overall, so the absolute total amount directed to the 'free distribution' channel has also declined; from an average of 43 kt yr⁻¹ in the 1st Regime to 28 kt yr⁻¹ in the 3rd. Furthermore, the proportion of food destroyed increased from 52% to 65% for the same regimes (though Regime 2 saw the highest average rate of destruction of 74%). This suggests the existence of institutional barriers to redistribution that need to be overcome.

One such barrier could be other EU regulations that may be perceived as having primacy over the concept of 'free distribution'. For example, only food that is deemed safe to consume should be permitted to be sold or otherwise distributed within the EU, or exported. Very explicitly, "food shall not be placed on the market if it is unsafe" (European Parliament and Council, 2002, art. 14, para. 1). However, what is "unsafe"? van der Meulen (2012) offers the interpretation on the language used as the EU accepting that the concept is a continuum, with regulation that puts more stock in being safe than avoiding unsafe. Bartl (2015) highlights the lack of clarity of defining terms used in EU food safety regulation. The result is potential uncertainty of interpretation within the 'grey area' between what are clearly 'safe' and 'unsafe' by actors within the EU's food supply chain. The highly perishable nature of fresh FFV could lead potential recipients and donors to avoid the risk of distributing food that is 'unsafe', even though it's condition may fall into the 'grey' area. Additionally, consumers may be unwilling to accept and/or feel slighted that they are being offered 'ugly food' that falls below a minimum acceptable visual 'quality' aesthetic (Aschemann-Witzel et al., 2017; de Hooge et al., 2017) – a concept we explore in a forthcoming paper. Destroying withdrawn food could be seen by the potential parties as being lower risk than taking on the responsibility of ensuring such food is 'safe', and therefore more acceptable. Eliminating this uncertainty could unlock the potential of using more withdrawn food that would otherwise be destroyed.

4.5. Lack of specific food waste policy and national legislation as an alternative

We have seen that reduction in food waste can be a result (intended or otherwise) of policy reform, as demonstrated by the CAP. Whilst food may be considered as a commons (Vivero-Pol, 2017), managing the sector from a market-facing perspective has resulted in less use of the withdrawal mechanism over the series of CAP reforms. However, the European Court of Auditors (2016) highlights that, whilst as early as 2011 the EU parliament was pushing the Commission for a concrete commitment to reduce food waste by half and provide leadership in action, little has been achieved. There is no specific EU policy on food waste, and policies that do exist are not fully aligned to combating food waste. Specifically including food waste in the next review of the CAP could address this.

It has thus far been up to individual Member States to take the initiative, something France and Italy did in 2016. As the González Vaqué (2017) comparative analysis illustrates, France's legislation focuses on raising awareness of actors at all stages of the food supply chain with a "clear food waste hierarchy", but also looks to "combat" food waste by emphasising prevention and imposing a general ban upon the practice. Critically, making food unsafe for the purpose of easy disposal is prohibited. Italy's legislation also focused on education and using donations as a channel to reduce food waste, but goes further by specifically incorporating the concept of doing so for "social welfare" purposes. It is too early yet to evaluate the effect of this legislation, though it should be area for inquiry in the medium term as data become available.

4.6. Brexit uncertainties & FFV waste

4.6.1. UK/EU FFV trade

In the current environment, it is appropriate to at least mention the impending departure of the UK from the EU. This is due to occur on 29 March 2019, two years after the UK triggered Article 50 of the Lisbon Treaty (UK Government, 2017). The data contained herein demonstrate the UK's use of the CAP's withdrawal mechanism has been minimal compared to other countries in the EU. Thus, the direct impact on quantity of withdrawals and destruction of food due to Brexit may also be minimal. However, the UK has a large trade deficit in fresh FFV; the UK exported just £199 m worth of fresh FFV in 2015, less than 4% of the value of imports (AHDB, 2016). Whether or not a comprehensive trade deal is agreed between the EU and UK before Brexit-date could have indirect effects on the use of the withdrawal mechanism and its climate cost.

A 'no-deal' situation would result in the trade between the UK and EU reverting to World Trade Organization, Most Favoured Nation (WTO MFN) rules, the most negative scenario for the UK economy (Miller, 2016, pp. 24–25). The quantity of fruit and vegetables imported by the UK from other EU countries in 2016 was 3.1 Mt (AHDB, 2016). The average WTO MFN tariff applied to fruit and vegetable products was 10.5% in 2016 (WTO et al., 2017, p. 82). Leaving the EU Single Market would see these tariffs imposed on FFV EU imports into UK. The estimated impact would be increasing costs to the UK consumer by 7–11%, whilst at the same time reducing net imports (by a non-specified amount) from the EU (van Berkum et al., 2016, pp. 30 & 33). EU producers may need to find alternative internal or export markets for any reduction in volume that would have gone to the UK should tariffs be re-imposed after Brexit. The Russian ban (Section 4.1) highlights how uncertainty can paralyse action. That ban has been in place since 2014, yet 'crisis prevention measures' permitting higher use of the withdrawal mechanism remained in place at the end of 2017. Should Brexit be viewed similarly if trade negotiations drag beyond March 2019 and/or there is a 'no-deal' outcome, it is conceivable that imports into the UK of EU FFV will decline (as costs rises). The EU could declare such events as a 'crisis' and invoke a relaxation of withdrawal limits, as it has done in response to the Russian ban.

4.6.2. Farm labour for harvesting in the UK

A second issue facing the UK food production under Brexit is having adequate labour. The UK's agricultural industry is highly reliant upon non-UK labour for harvesting; EU nationals comprise an estimated 98% of the seasonal labour in horticulture (European Union Committee, 2017, para. 253). A potential unintended consequence of the UK Government's Brexit negotiation's 'red line' of elimination of the free movement of people (Miller, 2017) could conceivably be a sudden loss of labour that is willing and able to undertake such activities within the agricultural sector. Without the necessary labour, there is a risk that a meaningful proportion of food produced within the UK will not be harvested at an optimal time (i.e. harvested early or late) or not harvested at all. The former may thus end up failing regulation and/or supermarkets' independent standards – ending up as inferior 'Classes' that command lower prices for the farmer. The consumer may also reject food that does not have the physical appearance they have become accustomed to. Such scenarios could lead to a greater levels of avoidable food loss, with a higher proportion of UK-produced food destroyed. The UK mainstream media has reported these scenarios as occurring during the 2017 harvest season, two years before Brexit (Daneshkhu, 2017; Simpson, 2017).

5. Conclusion

We have shown that EU policy can, and has, led to significant amounts of avoidable wastage of FFV and that this is associated with substantial production-phase GHG emissions. However, we have also

shown that reforms of policy, even of those not specifically focused on food waste, such as the CAP, can have a positive impact on reducing the volumes of such loss and waste. The successive iterations of the CAP have resulted in changes to the underlying CMO regimes. The changes have resulted in reduced amounts of food avoidably lost within the EU. The quantity of FFV withdrawn from markets is over 95% lower, with the embedded emissions of that FFV 90% lower, than 25 years ago. There is some way to go on reducing the proportion of those withdrawals that are destroyed. However, actions by Member States, such as France and Italy, to keep food loss and waste on the public agenda and legislative record show promise.

Whilst these are potentially positive steps towards institutionalising reductions in avoidable FLW, the EU has not abandoned all market interventions for agricultural produce. The current version of the CAP retains eight specific "crisis prevention and management" measures for fruit and vegetables (European Parliament and Council, 2013, art. 33, para. 3). Two of these measures, withdrawals and green/non-harvesting, continue to lead to destruction of edible food. The European Commission has also demonstrated willingness to set aside, at least temporarily, some of the withdrawal and destination policy limits and expectations for crises. Such 'short-term' solutions do not challenge the status quo, risking a 'back-sliding' of efforts for the EU to meet its own food waste reduction aspirations.

Through the course of conducting this research, a number of areas for further investigation have presented themselves. There appear to be institutional barriers preventing greater use of destinations for market withdrawals other than 'destruction' (e.g. 'free distribution'). Additionally, once there are sufficient data, an evaluation of the national legislation of France and Italy intended to combat and reduce the quantity food waste could prove useful for EU-level or other national-level policy. These are but two avenues of inquiry – the food loss and waste issue remains ripe with possibilities.

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